

What is needed to accept the new explanation of DAMA results

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ABSTRACT

The DAMA experiment clearly observes a small oscillatory signal. The observed yearly modulation is in phase with the Earth's motion around the Sun. Recent reference [Vavra, 2014] suggested that the DAMA experiment observes a WIMP of much smaller mass than what Xenon 10, Xenon 100, LUX and CDMS experiments can possibly reach. Scattering would occur on proton or oxygen target present in the NaI(Tl) crystal as OH-contamination at a few ppm level. This paper elaborates further on the idea that the OH-molecule could act as a very sensitive detection mechanism for neutrons or WIMPs, and suggests a calibration procedure to prove this idea. We also propose a new detector concept to detect a low mass WIMP.

Key words. DAMA experiment, Dark Matter search

1. Introduction

The fact that the DAMA's result [Bernabei, 2013] is not confirmed by other Dark Matter searching experiments, such as CDMS, Xenon-10, Xenon-100 or LUX, gave the author an idea that the DAMA signal is due to scattering of a low mass WIMP with proton or hydrogen atom. The hydrogen is present in a form of small OH-contamination in NaI(Tl) crystals. OH-molecules may come from the primary NaI salt and could be present at a level of ~few ppm. The important point to realize is that the OH molecule would be sensitive to very low energy neutrons and low mass WIMPs, i.e., collision of the WIMP and proton will cause vibrations of this molecule, which could be detected.

The question is what is needed to prove that this hypothesis is correct?

A low mass WIMP, for example $\sim 1 \text{ GeV}/c^2$, represents a real experimental challenge, as it requires a low mass target and extremely sensitive detector. The Dark Matter cloud is believed to be stationary relatively to the Galaxy. The Earth moves with a velocity of $230 \pm 30 \text{ km/sec}$ in the Galactic plane, and as a result, a $\sim 1 \text{ GeV}/c^2$ mass WIMP's kinetic energy oscillates between $\sim 0.353 \text{ keV}$ and $\sim 0.208 \text{ keV}$ relative to the DAMA experiment, on its yearly journey around the Sun. Figure 1 shows nuclear recoil energies as a function of recoil angle for various nuclei, assuming the WIMP mass of $1 \text{ GeV}/c^2$ WIMP. It is clear, that one prefers to use the proton target if the light WIMP mass is this small.

2. OH-impurity as a detector of WIMP

Fig. 2 shows a classical model of the signal formation in NaI(Tl) crystals. A deposited energy creates electron-hole pair, excites an electron into the conduction band, where it moves until it finds an activator (Tl), with a very low ionization potential of 6.108 eV , where the de-excitation occurs via small photonic emissions, mostly in visible spectrum [Knoll, 2010].

In this section we describe in more detail what are possible excitation of the OH-molecule [Vavra, 2014] and answer a question if resulting photons are detectable. Fig. 3 shows schemat-

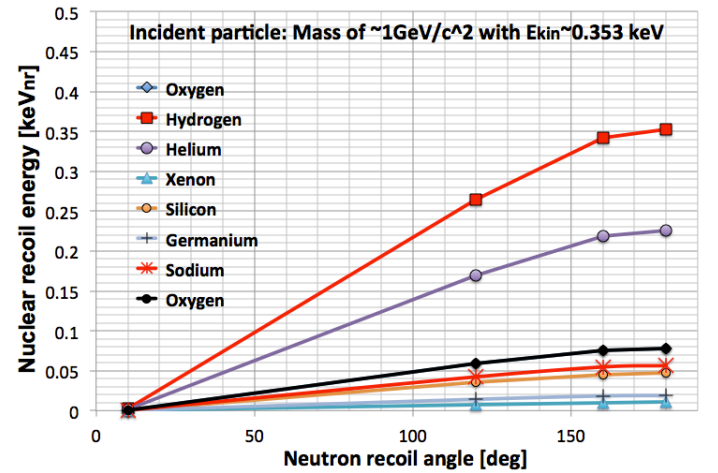


Fig. 1. Nuclear recoil energies for various nuclei assuming a $\sim 1 \text{ GeV}/c^2$ WIMP with kinetic energy of $\sim 0.353 \text{ keV}$.

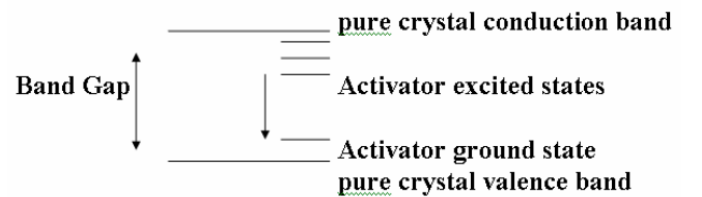


Fig. 2. Energy levels of NaI crystal with Tl-activator [Knoll, 2010].

ically energy levels in OH-molecule. If either a neutron or low mass WIMP hits a proton, or even an oxygen nucleus, in the OH molecule, it will cause vibrations and molecular excitations to higher energy levels. The molecule can then de-excite by fluorescent photons at either $\sim 282 \text{ nm}$ or $\sim 310 \text{ nm}$. Such photons can be detected by the Bialkali photocathode in principle, if one chooses the optical coupling correctly. Through this mechanism

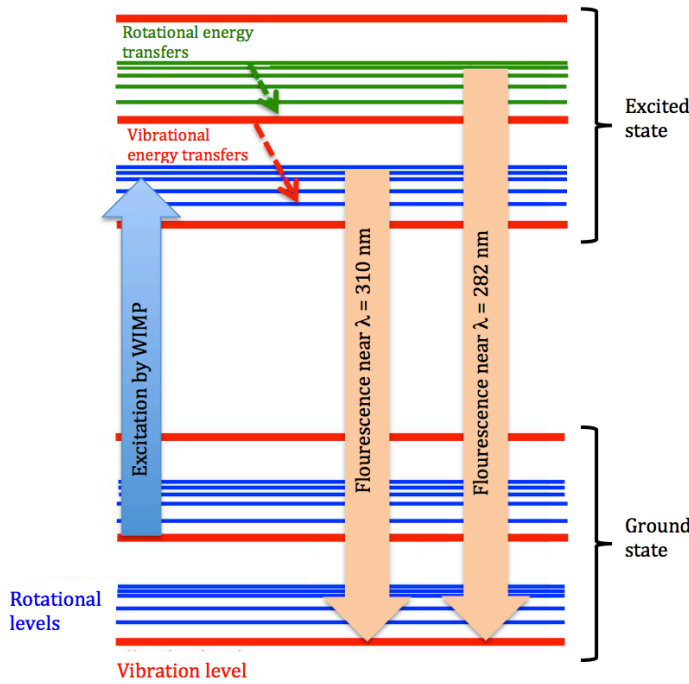


Fig. 3. Energy levels of OH-molecule are very complex. A low mass WIMP hits proton or even oxygen nucleus in the OH-molecule, causing excitation and subsequent photon fluorescence emissions near 310 or 282 nm, which are detectable by the Bialkali photocathode, if one uses the right optical coupling allowing transmission of these wavelengths. In principle a very low mass WIMP could be detected by this technique, as 282 nm corresponds to only 4.67 eV.

one could then increase the sensitive to extremely low sub-keV energy deposits.

One should mention that the OH-molecule was studied extensively by laser-induced fluorescence by many chemists. An example of such fluorescence measurement is the OH-molecule excitation by a 282 nm dye laser and in turn observing the 310 nm wavelength with a PMT with a notch filter [Smith, 1990]. They used this method to determine traces of OH-radicals in atmosphere [Matsumi, 2002].

One should also point out that 282 nm corresponds to 4.67 eV energy, which is a very small excitation compared to usual energy needed to excite NaI(Tl) crystal (~ 25 eV per electron-hole pair on average). This point plus a sensitivity to slow neutrons makes the OH-molecule excitation a very attractive idea to Dark Matter detectors. Just as one can pump the OH-molecule to excitation with a laser, one can excite it with WIMP collisions.

The NaI(Tl) crystal has a limit on maximum allowable OH-impurity level before its properties are affected. However there are other materials allowing a large OH-content, which could be investigated. For example the Corning 7980 Fused silica has 800-1000 ppm of OH-content by weight. One could perhaps consider enhancing the S/N ratio by implementing a notch filter to accept only wavelengths between 270 nm and 350 nm.

Figure 4 shows nuclear recoil energies as a function of recoil angle for various nuclei, assuming the WIMP mass of $4 \text{ GeV}/c^2$ WIMP. One can see that the recoil energy for proton is about the same that from oxygen, i.e., the WIMP collision with either proton or oxygen can excite the OH-molecule. One should note that

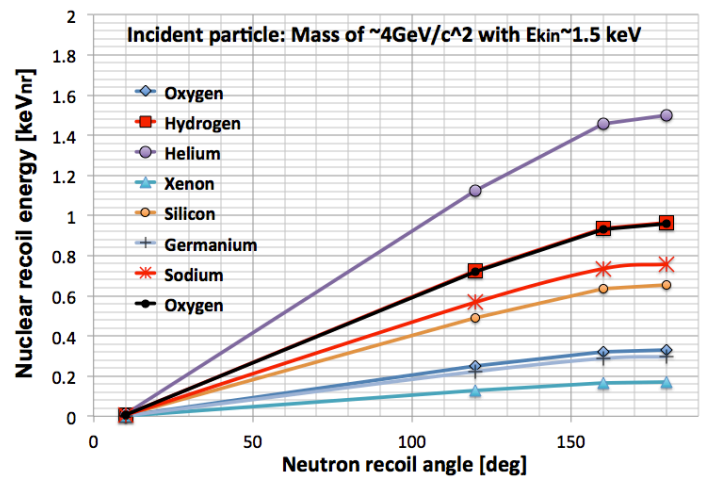


Fig. 4. Nuclear recoil energies for various nuclei assuming a $\sim 4 \text{ GeV}/c^2$ WIMP with kinetic energy of $\sim 1.5 \text{ keV}$.

a recoil energy of sodium nucleus is below DAMA's threshold of $\sim 1.5 \text{ keV}$.

3. Suggested steps to calibration the DAMA crystals

One has to show that the OH-molecule imbedded in NaI(Tl) crystals behave the same way as described in this paper. To prove the OH-hypothesis one should expose DAMA crystals to a very low energy sub-keV neutron beam and check the crystal response. If this result is positive, one can parameterize a dependence on the OH-content in small specially prepared NaI(Tl) samples with different OH-content. In addition, one could also use the laser-induced fluorescence method to quantify the OH-content in some DAMA crystals. There are chemists specializing in this methodology.

We believe that these calibration steps are necessary to understand the NaI(Tl) crystal response to very low energy proton recoils. One should not use the energy dependence obtained from the Gamma source calibration, as it will likely produce incorrect conclusions of the NaI(Tl) crystal response from sub-keV deposits of low mass WIMPs.

4. Conclusion

This paper provides arguments why the OH-molecule may be a good way to detect very low mass WIMP. It provides a method to reach the lowest possible WIMP mass. The paper suggests concrete steps the DAMA group could take to prove that the proposed idea is valid. The paper also suggests other ways to create a detector with large OH-content, which could be used for a detection of very low mass WIMPs.

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